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On-Line - WPI

(54) **Multipath signal equalizer with adaptive aerial array**

(57) In a GSM-type mobile telephone system, each unit includes an equalizer utilizing sync segments occurring within a window of predetermined length (eg 5 bit times, $0 \leq t \leq 4$) to correct a received signal for the effects of multi-path transmission. To deal with signals ($t > 4$) appearing outside the equalizer window, the basestation has an adaptive aerial array AE which is controlled so that its lobes (40, 41 fig.4) match the signal paths ($t=0$, $t=1\frac{1}{2}$) within the equalizer window and its interlobes (42) match the signal paths ($t=5$) which are outside the equalizer window. A within-limits sync segment signal is generated as the sum of the sync segments of the received signal components ($t=0$ to $t=4$) within the equalizer window. An adaptive algorithm unit iteratively adjusts the aerial pattern to maximize the ratio of the signals within and outside the equalizer window, by minimizing the difference between the within-limits sync segment signal and the sync segment in the received signal.

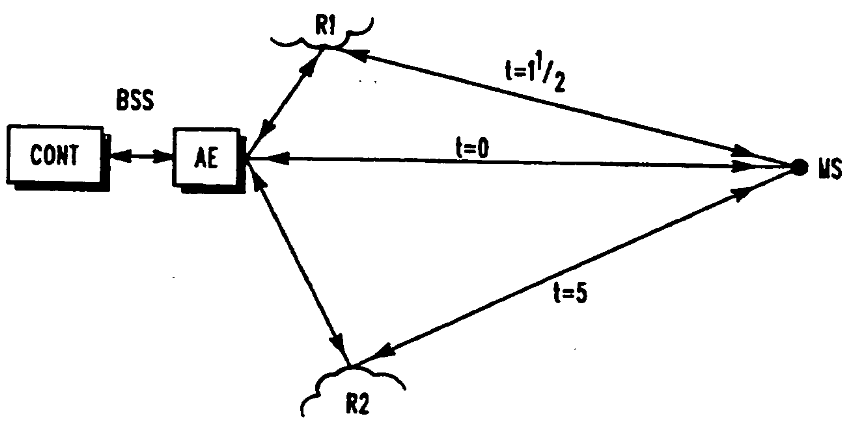

FIG.1

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

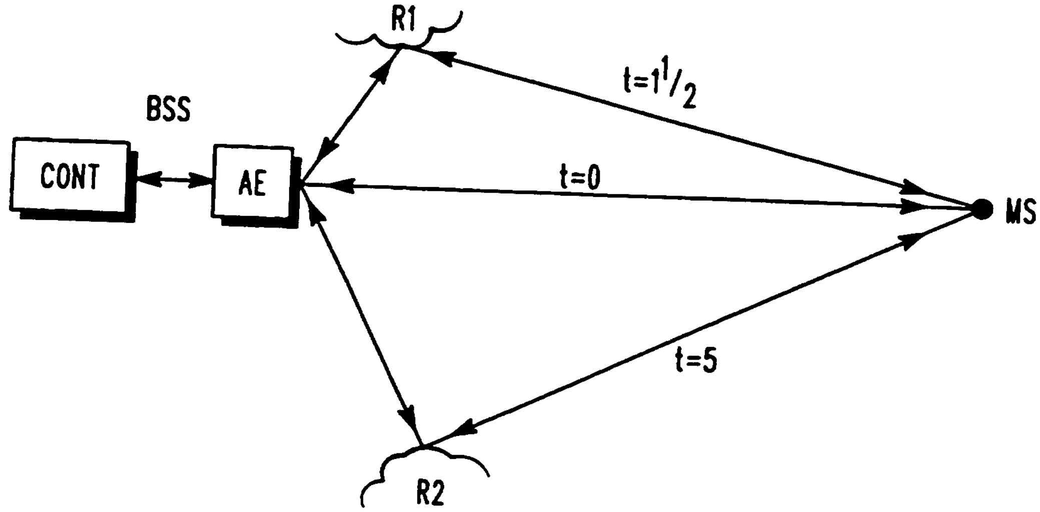

R1
BSS
CONT
AE
$t=1^1/_2$
t=0
MS
t=5
R2

FIG.1

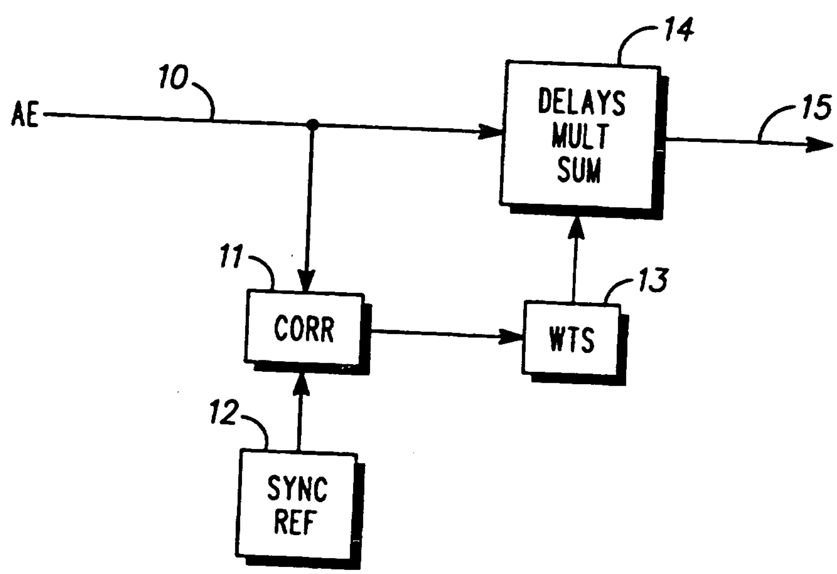

14
10
AE
DELAYS
MULT
SUM
15
11
13
CORR
WTS
12
SYNC
REF

FIG.2

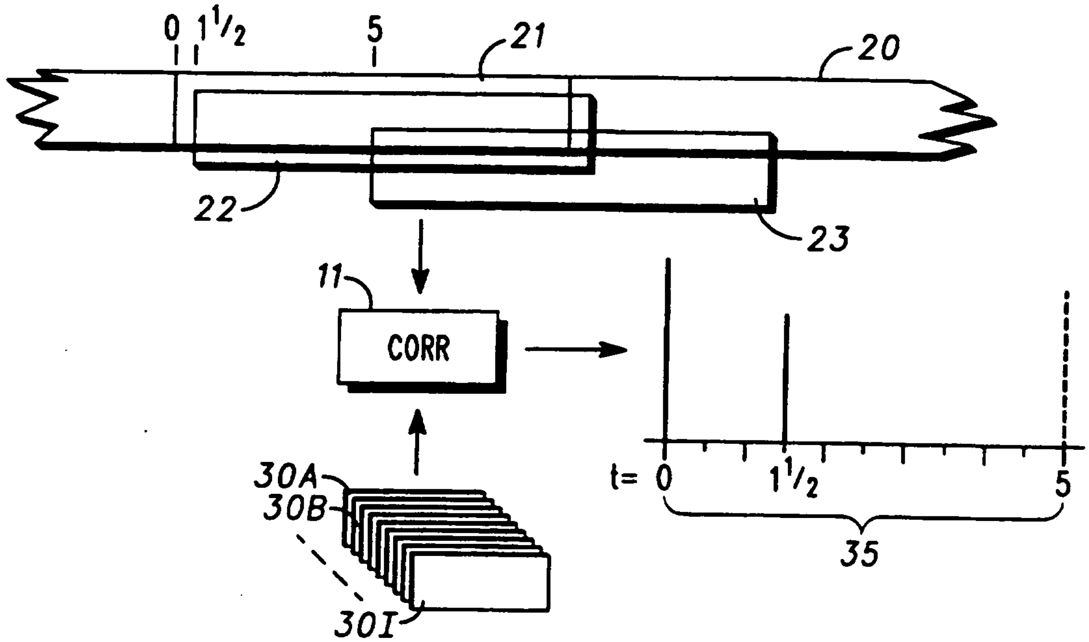

0
$1^1/_2$
5
21
20
22
23
11
CORR
30A
30B
30I
t= 0
$1^1/_2$
5
35

FIG. 3

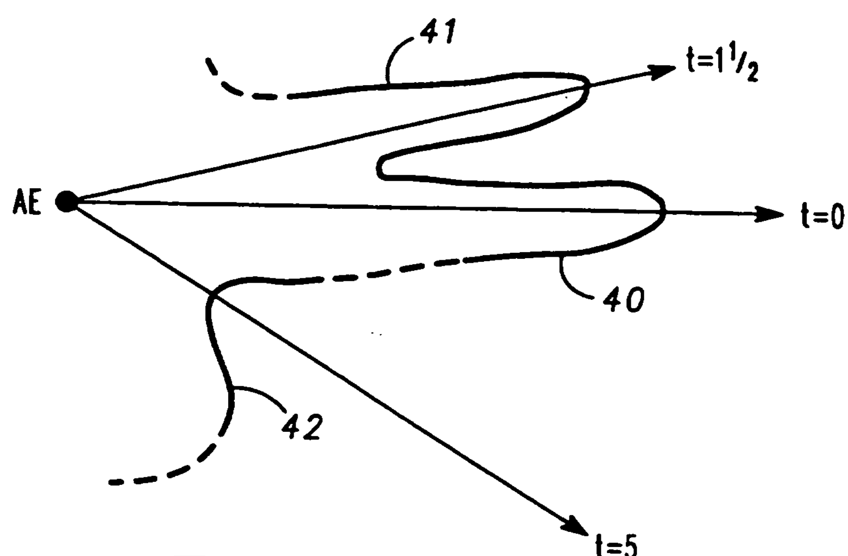
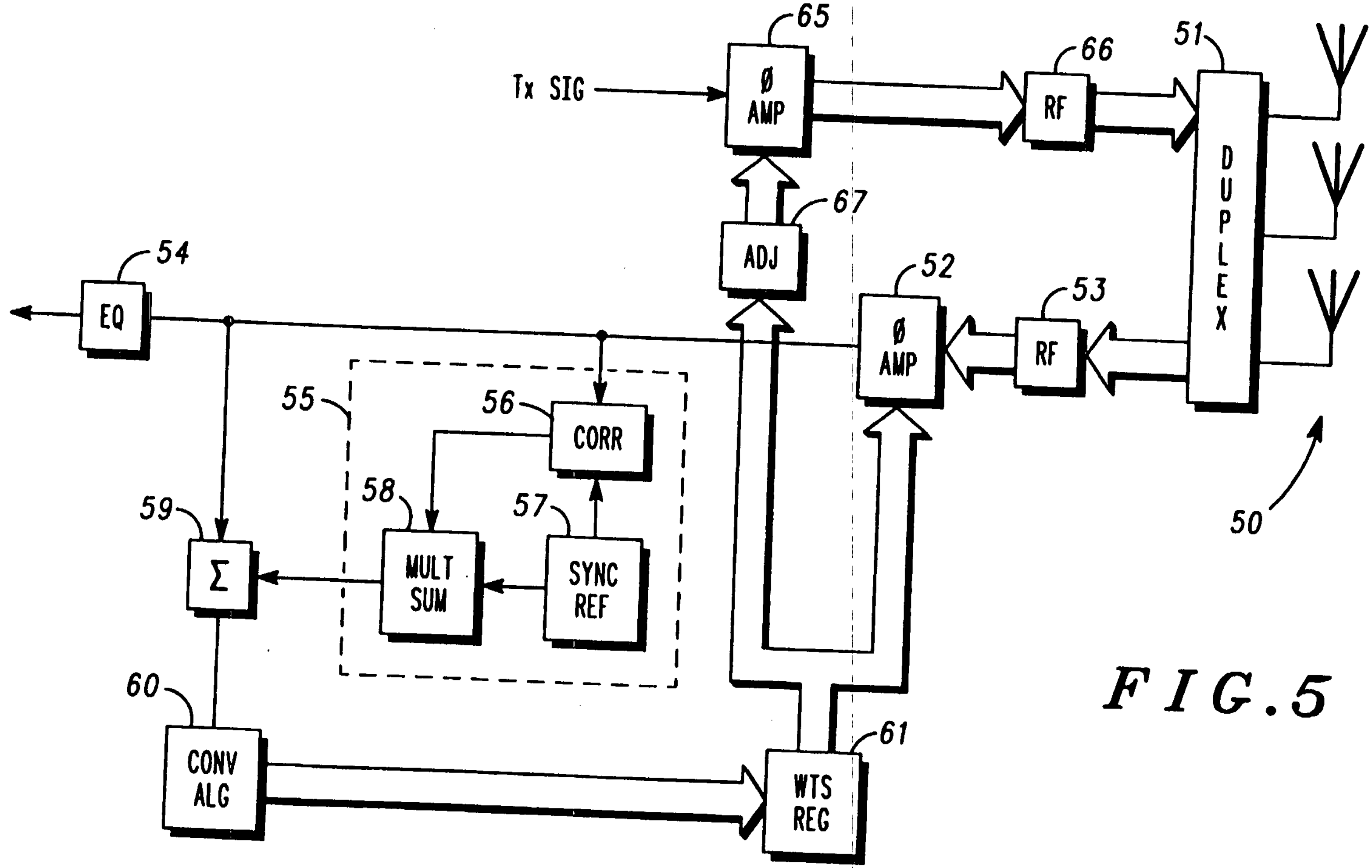

41
$t=1^1/_2$
AE
t=0
40
42
t=5

FIG. 4



Tx SIG
Ø AMP
RF
DUPLEX
ADJ
Ø AMP
RF
EQ
CORR
MULT SUM
SYNC REF
Σ
CONV ALG
WTS REG
50
51
52
53
54
55
56
57
58
59
60
61
65
66
67

FIG.5

Mobile Telephone Systems

Field of the Invention

The present invention relates to mobile telephone systems, and more particularly to digital systems incorporating mechanisms for minimizing the effects of multi-path transmission.

Background of the Invention

A cellular mobile telephone system, such as GSM (Global System for Mobile Communication), essentially comprises a set of basestations and a number of mobile stations or units. Each basestation is a combined transmitter and receiver station, for 2-way communication with the mobile units. The basestations are at fixed geographical positions, and the mobile units are generally portable units which can move relatively freely though the region covered by the basestations.

The area around a basestation within which it can communicate with mobiles is termed a cell. Since this area generally surrounds the basestation and the mobiles may be anywhere within the cell, the basestation uses non-directional or wide-angle antennas to receive signals from the mobiles, and similarly broadcasts its transmissions throughout the cell (or a wide segment of

the cell); the mobiles are omnidirectional (ie non-directional) for both transmitting and receiving.

On a featureless plain, the primary transmission path between the basestation and a mobile will normally be the direct path. However, various geographical features, such as mountains and large buildings, can reflect (re-radiate) signals and so produce additional transmission paths. These paths will be longer than the direct path, and will produce delayed versions or echoes of the signal. (The same effect in television is termed ghosting.)

The effects of such multi-path transmission may not be too serious in analog systems. In digital systems, however, the delays between different paths can very easily be larger than the bit period, and multi-path transmission can therefore cause major problems.

In a multiple access digital system, communication is normally set up between several units over a single channel. In a TDMA (time division multiple access) system, a single frequency channel is divided into a considerable number of time slots, each of which forms a separate communication channel (each time slot or channel being typically used for communication with a different mobile); in a CDMA (code division multiple access) system, codes are used to identify messages to different units.

A mobile therefore has to recognize or identify the bursts or data sequences directed to itself. For this, it must first receive the data sequences correctly. A data sequence is typically divided into a number of segments: an address segment, a data segment, and so on. The receiver must synchronize its operations with the received data sequence, and to assist in this, the data sequence normally contains a segment specifically designed to enable the receiver to achieve synchronization. We will term this sequence the synchronization or sync sequence. In the specific case of GSM systems, the sync sequence appears in the interior of the data sequence, and is termed a mid-amble, though in other systems it could of course form a preamble or even a postamble, or be superposed on the data in some other way (as in CDMA systems). (The sync sequence may serve other purposes as well.) We will term all such systems GSM-type systems.

Systems such as GSM incorporate means for counteracting the effects of multi-path transmission. The transmitted signal passes to the receiver over various different transmission paths, so several versions of the transmitted signal will be received by the receiver. Usually, the first version to be received will be that passing over the direct path, followed by one or more versions which are delayed and usually of lower amplitude. The received signal consists of the sum of these components of the combined signal as received over the various transmission paths.

The receiver obviously knows what the sync sequence pattern is for messages directed to it (the receiver). By correlating the sync sequence segment of the received signal with the sync sequence pattern, the receiver can therefore identify the time delays and amplitudes of the various versions of the transmitted signai, ie with the various components of the received signal. In a GSM system, for example, the sync sequence correlation is performed at half-bit-period intervals over 5 bit periods.

Once the correlation has been performed, the results are then used to correct the received signal. For each component, the received signal is delayed and has its amplitude and phase adjusted by the appropriate amount. These various delayed and adjusted signals are coherently summed, to form a corrected signal in which the contributions of the various components are combined. The corrected signal is the result of performing the corrections for all components, as determined by the correlations for those components. (Obviously some components may be negligible.) The correlation and correction process is termed equalizing.

Obviously, the parameters of the equalizing process will be set, as design constraints, for any particular system. In the GSM system, for example, as noted above, 9 correlations are performed, at half-bit-period intervals. The GSM bit rate is approximately 270 kHz, so

for that system, the correlation "window" is about 18 ¢sec. This time corresponds to about 5 km, so the GSM system can accommodate path differences, in multi-path transmission situations, of up to 5 km.

In most situations, this is more than adequate; paths involving reflections tend not to deviate greatly from the direct path, and paths differences tend to be well under 5 km. However, there are some situations where large path differences can occur, such as in mountainous regions. Further, in such regions the direct path may suffer considerable attenuation, so that indirect (reflection) path signals, ie delayed signals, may be of comparable amplitude to the direct signal. The equalizing technique described above cannot cope with such situations, ie situations where the signal delays exceed the system design limits.

An alternative technique for dealing with multi-path transmission problems has also been proposed, consisting of using an adaptive aerial. Such an aerial is a multi-element aerial in which the power and phase of the different elements can be controlled, allowing the directional pattern of the aerial to be controlled. For transmission, the signal to be transmitted is divided between the different aerial elements, with the power and phase of the components fed to the different elements being individually controlled; for reception, the signals received by the different elements are combined, with the power and phase of the signals from the

different elements being similarly controlled before they are combined. (The power and phase parameters for the elements for a given directional pattern vary with frequency, in a straightforward way.)

To use this technique in a mobile telephone system, the aerial is controlled to radiate primarily in the direction of the mobile. This increases the power transmitted towards the mobile; it also reduces the power transmitted in other directions, so reducing the effect of reflective paths to the mobile (since those paths normally start at some appreciable angle to the direction of the mobile). The desired signal strength at the mobile is thus increased, and the potentially interfering reflective path signals are decreased. For reception, the sensitivity of the receiver to signals direct from the mobile is similarly increased and the sensitivity to reflection path signals is similarly decreased.

It is of course necessary to determine the direction of the mobile. This can be done, for example, by operating the aerial array initially with a non-directional pattern, and then gradually changing the pattern towards a directional or single-lobed form, rotating the lobe to find the greatest signal strength, further tightening the lobe, and oscillating the lobe gently to maintain it on the mobile and track any transverse movements of the mobile.

This technique, however, is incompatible with the equalizing technique used in GSM and similar systems. The adaptive aerial technique involves directing the aerial array pattern towards the mobile so that only the direct path is used. The performance of a GSM-type system is improved over a standard or simple system by the use of the correlation and correction technique to combat the effect of multi-path transmission. If the adaptive aerial technique is used, the equalizing correction procedure becomes superfluous, and the full advantages of the GSM-type technique is lost.

The general object of the present invention is to provide a technique for dealing, in GSM-type systems, with situations where reflected path signals may have delays longer than the window of the equalizer.

Summary of the Invention

The crux of the present invention lies in controlling an adaptive aerial array so that its lobes match the signal paths within the equalizer window and its interlobes match the signal paths outside the equalizer window. The lobe matching is for phase as well as amplitude; the interlobe phases are of course irrelevant.

It is preferred to use an adaptive algorithm which iteratively adjusts the aerial pattern to maximize the ratio of the signals within and outside the equalizer window. To achieve this, it is convenient to generate a

within-limits sync segment signal is the sum of the sync segments of the received signal components within the equalizer window, and minimize the difference between this and the sync segment in the received signal.

Brief Description of the Drawings

A basestation embodying the present invention will now be described, by way of example, with reference to the drawings, in which:

Fig. 1 shows a basestation, a mobile, and typical transmission paths;

Fig. 2 is simplified block diagram of an equalizing circuit;

Fig. 3 is a set of waveforms showing the principle of equalization;

Fig. 4 is an antenna pattern related to the Fig. 1 transmission paths; and

Fig. 5 is a more detailed block diagram of the basestation.

Detailed Description of an Embodiment

Fig. 1 shows a basestation BSS consisting of a control unit CONT and an aerial AE, a mobile station MS, and two large reflecting bodies R1 and R2 which may be, for example, a large building and a mountain. There are 3 signal paths between the basestation and the mobile; a direct path and two reflection paths involving reflections

from the reflecting bodies R1 and R2. The direct path is labelled "t=0" because its signals are the first to arrive and form a reference or zero point from which the times of signals along other paths may be measured. The two reflection paths are labelled "t=1è" and "t=5", indicating that their signals arrive respectively 1è and 5 bit times after the direct path signal.

The system is symmetrical, in that signals from the basestation to the mobile follow much the same paths as signals from the mobile to the basestation.

Fig. 2 is simplified block diagram of an equalizing circuit, and Fig. 3 is a set of waveforms showing how equalization operates. Referring first to Fig. 3, 20 is a signal sequence or burst, which includes a sync segment 21. This is in fact a mid-amble, which is preceded and followed by other segments of the signal sequence. This signal sequence 20 can be regarded as the transmitted signal.

The received signal consists of 3 components, the t=0, t=1è, and t=5 components. The signal sequence 20, in addition to being regarded as the transmitted signal, can also be regarded as the direct path component of the received signal. The sync segments of the remaining 2 components of the received signal are shown as 22 and 23, being delayed by 1è and 5 bit times respectively from the direct sync segment 21. (The remaining segments of the delayed components are not shown.)

These 3 components will of course normally have different amplitudes, and the actual received signal will of course be the sum of these 3 components.

The sync segment is of course known, and it is assumed that the timing of the received signal (ie the timing of its leading component, the direct (t=0) component) is also known. The receiver generates 9 copies 30A-30I of the sync segment at successive half-bit times (eg by successive delays), with the first segment coinciding with the timing of the received signal. Thus the internal sync segment 30 is synchronized with the direct path component 21 of the received signal, and the remaining internal sync segments 31-34 follow at successive half-bit times.

In the equalizing circuit (Fig. 2), the received signal from the aerial appears on line 10, and the 9 internal sync segments are generated by a sync reference circuit 12. The received signal and the 9 internal sync segments 30A-30I are correlated by a correlator 11. This involves, for each correlation, bit by bit multiplication followed by addition of the products. The result is a set of 9 correlation coefficients, showing the relative strengths of the 9 possible received signal components (from t=0 to t=5). In Fig. 3, the amplitudes of these correlation coefficients are shown at 35, with that for t=0 being the largest, that for t=1è being substantial, and those for t = è, 1, 2, 2è, 3, 3è, and 4 being

insignificant. THe coefficients are in fact complex, having phase as well as amplitude.

Returning to the equalizing circuit of Fig. 2, the received signal is also passed to a matched filter circuit 14. In this circuit, 9 delayed versions of the received signal with delays of 0 to 4 bit periods (the original received signal being regarded as a delayed signal with zero delay) are generated. Each of these 9 delayed signals is multiplied by the corresponding correlation coefficient; that is, its amplitude and phase are appropriately adjusted. The resulting 9 signals are then summed, to yield an equalized signal which is a close replica of the original transmitted signal.

Of course, this equalizing system has various elaborations in practice. For example, the correlation coefficients are suitably updated to take account of changes in the components of the received signal resulting from movement of the mobile MS and resulting changes in the reflection paths; and the equalizer has a function known as a veterbi part, which is required for demodulation. But these elaborations are not relevant to present purposes.

This equalizing circuit copes with signal components which are delayed by up to 4 bit times. However, as discussed above, in certain situations there may be components which are delayed by more than 4 bit times. Fig. 3 shows the sync segment of such a component 23,

with a delay of 5 units. If a correlation coefficient is calculated for this component, it will be of substantial size, as indicated in Fig. 3. However, the parameters of the system being considered do not permit this, and this component will therefore act as a major source of noise.

The present system is designed to accept components which are delayed within the system parameter limit but to reject components which are delayed by more than that limit. This is achieved by setting the adaptive aerial array to perform spatial filtering. In general, reflective signal paths having different delays will have different angles at the antenna, so the antenna pattern can be adjusted to have lobes in the direction of signal paths with within-limits delays and interlobes in the direction of signal paths with outside-limits delays.

Fig. 4 shows an antenna pattern adjusted appropriately to the transmission path pattern of Fig. 1. The two paths t=0 (the direct path) and t=1è are within-limits paths, and the path t=5 is an outside-limits path. A suitable antenna pattern will have a lobe 40 in the direction of the t=0 path, a lobe 41 in the direction of the t=1è path, and an interlobe or near-null 42 in the direction of the t=5 path. In effect, the aerial pattern is adjusted to perform spatial filtering of the various components of the received signal. For this, an algorithm is used which operates to maximize the combination of the desired (ie within-limits) signals relative to other signals. These other signals will of course include

outside-limits signals from the same source as the within-limits signals, but may also include other signal sources (ie general noise and interference).

Referring to Fig. 5, the basestation BSS comprises an aerial array AE consisting of a plurality of aerial elements 50; typically, there may be 10 such elements, forming an array whose size may typically be around 5 wavelengths (for the mid-band frequency). These are coupled through a duplexer unit 51 to an RF stage 53, which sums, amplifies, and demodulates them (preserving their phase). The RF stage feeds an adjustment unit 52, in which the phase and amplitude of each aerial signal can be adjusted according to a respective weight (or more accurately an amplitude weight and a phase shift), and the adjusted signals are summed to produce a single received signal, which is equivalent to the received signal on line 10 of the Fig. 2 circuit. This received signal is passed to an equalizer unit 54, which may be the Fig. 2 circuit, and is also used to generate the set of weights which control the adjustment unit 52.

From the received signal, a corresponding within-limits sync segment signal has to be generated. The actual received signal is as illustrated at the top of Fig. 3, consisting of the sum of all received components (the t=0, t=1è, and t=5 components in this case). The within-limits signal is the sum of the components within the system parameters, ie the sum of the t=0 and t=1è signals (with their respective amplitudes and phases). The

within-limits sync segment signal is the within-limits signal for the sync segments only; the remainder of the received signal (ie the other segments and the outside-limits components) is irrelevant for this purpose.

The within-limits sync segment signal is generated by a circuit 55, which consists of a correlator 56, a sync reference unit 57, and a weighting and summing unit 58. The correlator 56 and the sync reference unit 57 are identical to the correlator and sync reference circuit of the equalizer circuit 54 (and of Fig. 2), and may in fact be those units. The weighting and summing unit 58 is broadly similar to the matched filter circuit 14.

More specifically, the sync reference unit 57 generates the 9 copies of the sync segment, the first being synchronized with the sync segment of the $t=0$ component of the received signal and the remaining 8 copies being delayed by è, 1, é, and 4 bits from the first copy. The correlator 56 produces the correlation signals for the 9 comparisons of the received signal with the 9 versions of the sync segment. The 9 copies of the sync segment generated by the sync reference unit 57 are fed to the weighting and summing unit 58. In this unit, each of the 9 sync segments from the sync reference unit 57 is multiplied by the corresponding correlation coefficient or weight (amplitude and phase) from the correlator 56, and the 9 products are summed. The result is the within-limits sync segment signal.

This signal and the received signal from the receiver unit 53 are fed to a summing unit 59, which subtracts the within-limits sync segment signal from the received signal. The resulting signal from this unit is the outside-limits components of the sync signal. This can be regarded as an error signal, since it consists of those components which the system is trying to minimize. This error signal is fed to an algorithm unit 60, which generates a set of aerial weights which are passed to a weights register 61. It is the weights in this register which control the adjustment unit 52, as discussed above.

It is found that the error depends reasonably smoothly on the amplitudes and phases of the weights, and various reasonably simple algorithms may be used by the algorithm unit 60. The algorithm unit 60 may for example operate an iterative convergence algorithm of the LMS/LMSE (least mean squares/least mean squares error) type which tries to adjust the sync segment of the received signal and the within-limits sync segment signal to match each other. A convenient measure of the degree of match is the root mean square; the square root of the sum of the squares (or simply the sum of the squares) of the differences between the corresponding bits of the two signals, over the length of the sync section of the received signal, should be minimized.

With the LMS algorithm, the weights are iteratively adjusted to minimize the error signal. As the system converges to the minimum, the aerial pattern will

approach that shown in Fig. 4, and the amplitude of the outside-limits components of the received signal will decrease. (The correlation coefficients of the within-limits components are also likely to change somewhat during this process.)

Alternatively, some other algorithm such as a block algorithm can be used. In this, the effects of various weight adjustments are first determined and then a matrix inversion technique is used to determine the required weights. This is essentially non-iterative, although the procedure can be repeated if desired if the initial error is extremely large.

For transmission, the same aerial pattern is used to concentrate the transmitted beam into the within-limits paths and to minimize the beam strength in the outside-limits paths. The signal to be transmitted is fed to an adjustment unit 65, which generates the signal components for the elements 50 of the aerial array, adjusting the phase and amplitude of each component according to a respective weight (or more accurately an amplitude weight and a phase shift). The modulated signals are passed to an RF stage 66, which modulates them at the carrier frequency, and thence to the aerial array 50 (via the duplexer 51).

The weights are obtained from the weights register 61. Since the transmitter frequency is different from the receiver frequency, the weights require appropriate

adjustment to achieve the same aerial pattern, as mentioned above. This adjustment is performed by a transmitter weights adjustment unit 67.

It will be realized that this process does not involve any explicit determination or representation of the directions of the various signal paths. It should also be noted that a knowledge of these directions would not by itself be sufficient, since to perform the present spatial filtering, the phases of the various components have to be appropriately adjusted, and the phase of a component is not determined by its direction.

The system has been described with reference to a planar aerial array; in practice, the elements of the aerial array will be designed to concentrate the aerial pattern near the horizontal plane. The principles, however, can obviously be extended to adjusting the aerial pattern in the vertical as well as the horizontal plane.

Claims

1 A basestation, in a mobile telephone system of the type where each unit includes an equalizer utilizing sync segments occurring within a window of predetermined length to correct a received signal for the effects of multi-path transmission, characterized in that the basestation has an adaptive aerial array which is controlled so that its lobes match the signal paths within the equalizer window and its interlobes match the signal paths outside the equalizer window.

2 A basestation according to claim 1 characterized by means for generating a within-limits sync segment signal comprising the sum of the sync segments of the received signal components within the equalizer window, and in that the adaptive algorithm means includes means for minimizing the difference between the within-limits sync segment signal and the sync segment in the received signal.

3 A basestation according to either previous claim characterized by adaptive algorithm means for iteratively adjusting the aerial pattern to maximize the ratio of the signals within and outside the equalizer window.

4 A basestation, in a mobile telephone system of the type where each unit includes an equalizer utilizing sync segments occurring within a window of predetermined length to correct a received signal for the effects of multi-path transmission, substantially as herein described.

5 Any novel and inventive feature or combination of features specifically disclosed herein within the meaning of Article 4H of the International Convention (Paris Convention).

The Patent Office

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Application No: GB 9621996.9
Claims searched: 1 to 4

Examiner: Mr Jared Stokes
Date of search: 17 January 1997

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): H1Q (QFF, QFH, QFJ)
H4L (LDC, LDDSF, LDDRS, LDDSX, LFND)

Int Cl (Ed.6): H01Q (3/26, 3/34)
H04B (7/005, 7/10)
H04L (1/02, 1/06)

Other: On-Line - WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	EP 0 582 233 A1 (NEC) See whole document, esp. claim 1	-
A	US 5 260 968 (Gardner) See whole document, especially abstract	-

X Document indicating lack of novelty or inventive step
Y Document indicating lack of inventive step if combined with one or more other documents of same category.
& Member of the same patent family

A Document indicating technological background and/or state of the art.
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